No. XXVI. — A PHENOMENON OF ELECTRICAL CONVECTION.

By James Jay Greenough.

Presented June 9, 1880.

While studying the spectra formed by passing a spark from an induction coil through heated media, I perceived that, when the negative terminal consisted of a very fine platinum wire, the passage of the sparks made it glow, and soon fused it. Supposing that the heating effect was due to the resistance offered by the fine platinum wire, I joined the two terminals and allowed the induced current to flow through the circuit uninterrupted. No heating effect was produced. The phenomena is a very marked one, and the incandescence of the platinum gives a brilliant star of light.

This effect seems to be due to the impact of the particles of matter upon the negative terminal, and is related to the electrical convection effects first studied by Prof. Rowland. It can also be termed a Crookes effect under ordinary atmospheric pressure, for the electrified stream of molecules urged with great energy, rebound from the point of the negative terminal, and, being confined by the stratum of gases, expend their *vis viva* in repeated blows upon the terminal, which is raised thereby to incandescence.

No. XXVII. — THE EARTH AS A CONDUCTOR OF ELECTRICITY.

By John Trowbridge.

Presented June 9, 1880.

The Observatory of Harvard University transmits time signals from Cambridge to Boston, a distance of four miles. The regular recurrence of the beats of the clock at the Observatory affords a good means of studying the spreading of the electrical current from the terminal of the battery, which is grounded at the Observatory; and the establishment of the telephone dispatch companies in Boston and Cambridge, with their various ground connections, gave me unusual means of studying this spreading.

In all the telephone circuits between Boston and Cambridge, and

in Cambridge alone, in the neighborhood of the direct line between Boston and Cambridge, the ticking of the Observatory clock can be heard. This transmission of the time signals to the various telephone stations has been attributed to the proximity of the telephone circuit wires to the time wires from the Observatory. This is evidently an erroneous conclusion, as will be seen from a short mathematical consideration.

The expression for the induction produced in one wire by making and breaking a current in a parallel wire* is $R_2\, y_2 = \pm\, M y_1$, in which y_2 represents the induced current, R_2 the resistance of the circuit which conveys this induced current, M the coefficient of induction between the parallel circuits, and y_1 the current in the primary circuit, the interruption of which produces the induced currents.

Now $M = \int\!\!\int \frac{ds\, ds'}{r}$, in which ds and ds' are elements of the parallel wires, and r is the perpendicular distance between them. The value of M in the case we are considering is $M = \frac{A^2}{r}$, in which A represents the length of the parallel wires, along which the induction takes place, and r is the distance between the wires. We shall therefore have

$$R_2\, y_2 = \pm\, \frac{A^2}{r}\, y_1. \qquad \text{Eq. (1)}$$

Now the electromotive force of the induced current y_2 is very much greater than that of the inducing current y_1, and in order that the current strength y_2 should be able to develop even a small electro-magnetic effect in the receiving telephone, the coefficient of induction $\frac{A^2}{r}$ must be large, or in other words the distance along which the lines run parallel must be great, and the distance r between these lines must be small. An arithmetical consideration of Eq. (1) will convince one that, with telephones of the resistance usually employed (50 units) no inductive effect will be perceived, by the employment of even ten quart Bunsen cells, between wires which run parallel to each other a foot apart for the distance of thirty or forty feet. In order to detect an inductive effect under these conditions, a telephone of three or four units of resistance and a large battery must be employed. With a telephone of 30 or 40 units of resistance similar to those employed on district circuits, no induction can be perceived under the conditions we have prescribed.

For still stronger reasons it is impossible to hear telephonic messages

* Maxwell's Electricity and Magnetism, ii. 209.

by induction from one wire to another, unless the two wires between which induction is produced run parallel and very near to each other a long distance. This distance generally exceeds the distance at which the ordinary Bell telephone ceases to transmit articulate speech. The effects which have usually been attributed to induction on telephone circuits are due to the earth connections and to imperfect insulation. Indeed, there would be no trouble from induction if telephone wires were enclosed in a cable; for a consideration of Eq. (1) will make it evident that the telephonic messagess transmitted over one wire, on account of the feeble currents which produce them, would have no practical effect upon the neighboring wires enclosed with it.

Since the transmission of the time signal service of Harvard College Observatory through all the telephone circuits in Boston and Cambridge is evidently not due to induction, but to tapping, so to speak, the earth at points which are not at the same electric potential, it was an interesting question to study the extent of the equipotential surfaces formed around the grounds of the time service circuit at Cambridge and in Boston. In this survey I was greatly assisted by Mr. G. H. Francis and Mr. H. C. French.

I speedily discovered that the time signals could be distinctly heard in a field an eighth of a mile from the Observatory, where one ground of the time circuit is located. The method of exploration consisted in running a wire five or six hundred feet along the grass, grounding its ends in moist earth, and including a telephone in the circuit. On completing the circuit through the telephone and the ground the evidence of an electrical current was plainly apparent from the ticking which making and breaking the circuit produced in the telephone, and the signals of the Observatory clock were distinctly heard. At the distance of a mile from the Observatory and not in the direct line between the Observatory and the Boston office, the time signals were obtained by tapping the earth at points only fifty feet apart. At a distance of five hundred feet directly behind the Observatory, no points five hundred feet apart could be found which were not practically at the same potential. The survey was carried to a distance of a mile behind the Observatory grounds with negative results. At points one mile from the central line between the Observatory and the Boston office the time signals could not be heard on the trial wire of six hundred feet. This was to be expected, since the trial wire should have its length increased as the distance from the grounds of the battery increases, in order to permit of one end of the wire touching a point of much higher potential than the other.

The theoretical possibility of telegraphing across large bodies of water is evident from this survey which I have undertaken. The practical possibility is another question. At no point in the survey did I find an absence of earth currents. The peculiar crackling noises heard in telephones are due to earth currents, and not to fluctuations in the batteries employed on telephone circuits; for they were characteristic of the circuits employed by me in which the earth was used as a part of the circuit, and were absent when a battery circuit was closed without the intervention of the earth. The tick produced in the exploring telephone whenever the circuit was closed through the ground was due to earth currents, and not to polarization between the copper wire and the wet earth; for it was many hundred times stronger than the polarization effects produced by dipping the copper terminals of the telephone wire in acidulated water. This crackling noise produced by the earth currents in a telephone is a curious phenomenon, and shows that the earth currents have a rapidly intermittent character which escapes observation by any other instrument. A delicate electro-dynamometer, for the registration and observation of these intermittent earth currents, is much to be desired. In some cases the pulsatory effect of these earth currents was very marked. At no point which I explored were evidences of earth currents absent.

In a discussion of the earth as a conductor Steinheil says: "We cannot conjure up gnomes at will, to convey our thoughts through the earth. Nature has prevented this. The spreading of the galvanic effect is proportional, not to the distance from the point of excitation, but to the square of this distance; at the distance of fifty meters only exceedingly small effects can be produced by the most powerful electrical effects at the point of excitation. Had we means which could stand in the same relation to electricity that the eyes stand to light, nothing would prevent our telegraphing through the earth without telegraph conductors, but it is not probable that we shall ever attain this end." *

Theoretically, however, it is possible to-day to telegraph across the Atlantic Ocean without a cable. Powerful dynamo-electric machines could be placed at some point in Nova Scotia, having one end of their circuit grounded near them and the other end grounded in Florida, the conducting wire consisting of a wire of great conductivity, and being carefully insulated from the earth except at the two grounds. By exploring the coast of France, two points on two surfaces not at

* Dub. Anwendung des Elektromagnetismus, p. 172, 1873.

the same potential could be found, and by means of a telephone of low resistance the Morse signals sent from Nova Scotia to Florida could be heard in France. With the light of our present knowledge the expenditure of energy on the dynamo-electric engine would seem to be enormous.

The points made in this paper are as follows: —

1. Disturbances in telephone circuits usually attributed to effects of induction are, in general, due to contiguous grounds of battery circuits. A return wire is the only way to obviate these disturbances.

2. The well-defined equipotential surfaces in the neighborhood of battery grounds show the theoretical possibility of telegraphy across bodies of water without the employment of a cable, and leads us to greatly extend the practical limit set by Steinhill.

3. Earth currents have an intermittent character, with periods of maxima and minima, which may occur several times a minute during the entire day.